Office de la propriété intellectuelle du Canada

Un organisme d'Industrie Canada

Canadian Intellectual Property Office

An Agency of Industry Canada

Bureau canadien des brevets

Certification

La présente atteste que les documents ci-joints, dont la liste figure ci-dessous, sont des copies authentiques des documents déposés au Bureau des brevets.

Canadian Patent Office

Certification

This is to certify that the documents attached hereto and identified below are true copies of the documents on file in the Patent Office.

Specification and Drawings as originally filed, with Application for Patent Serial No: **2,328,759**, on December 19, 2000, by **JDS UNIPHASE INC.**, assignee of Thomas Ducellier, for "Optical Switch".

Agent certificateur/Certifying Officer

January 13, 2004

Date

Canada

(CIPO 68)
04-09-02

OPIC CIPO

OPTICAL SWITCH

Field of the Inv ntion

The present invention relates to the field of optical switches.

Background of the Invention

Optical matrix switches are commonly used in communications systems for transmitting voice, video and data signals. Generally, optical matrix switches include multiple input and/or output ports and have the ability to connect, for purposes of signal transfer, any input port/output port combination, and preferably, for N x M switching applications, to allow for multiple connections at one time. At each port, optical signals are transmitted and/or received via an end of an optical waveguide. The waveguide ends of the input and output ports are optically connected across a switch interface. In this regard, for example, the input and output waveguide ends can be physically located on opposite sides of a switch interface for direct or folded optical pathway communication therebetween, in side-by-side matrices on the same physical side of a switch interface facing a mirror, or they can be interspersed in a single matrix arrangement facing a mirror.

Establishing a connection between a given input port and a given output port, involves configuring an optical pathway across the switch interface between the input ports and the output ports. One way to configure the optical pathway is by moving or bending optical fibers using, for example, piezoelectric benders.

Another way of configuring the optical path between an input port and an output port involves the use of one or more moveable mirrors interposed between the input and output ports. In this case, the waveguide ends remain stationary and the mirrors are used for switching. The mirrors can allow for two-dimensional targeting to optically connect any of the input port fibers to any of the output port fibers.

An important consideration in switch design is minimizing switch size for a given number of input and output ports that are serviced, i.e., increasing the packing density of ports and beam directing units. It has been recognized that greater packing density can be achieved, particularly in the case of a movable mirror-based beam directing unit, by folding the optical path between the fiber and the movable mirror and/or between the movable mirror and the switch interface. Such a compact optical matrix switch is disclosed in U.S. Patent No. 6,097,860. In addition, further compactness advantages are achieved therein by positioning control signal sources outside of the fiber array and, preferably, at positions within the folded optical path selected to reduce the required size of the optics path.

Current switch design continuously endeavors to provide smaller optical switches.

However, in the current approach for optical switching between reflection means, the beam follows a "Z-shaped" path between the optical elements. Thus, by providing an in-line arrangement of the optical components a more compact optical switch can be provided.

It is an object of the present invention to provide an optical switch having an in-line arrangement of optical components.

It is an object of this invention to provide a more compact optical switch.

Another object of this invention is to provide a compact optical switch based on deflection means in transmission.

Summary of the Invention

In accordance with the invention there is provided an optical switch comprising: at least one input port for launching a beam of light into the optical switch; at least two output

ports for selectively receiving the beam of light from an optical path between the at least one input port and a selected one of the at least two output ports; a lens having a focal length approximately equal to the near zone length of the beam of light incident thereon; a first array of deflectors including a first fixed deflector and a first plurality of independently tiltable deflectors and a second array of deflectors including a second fixed deflector and a second plurality of independently tiltable deflectors, wherein the first fixed deflector is for receiving the beam of light from the at least one input port via the lens and for deflecting the beam of light to one of the second plurality of independently tiltable deflectors via the lens, and the second fixed deflector is for receiving the beam of light from one of the first plurality of independently tiltable deflectors via the lens and for deflecting the beam of light to a selected one of the at least two output ports via the lens, and wherein the first and the second plurality of independently tiltable deflectors are for switching the beam of light.

In accordance with the invention there is further provided an optical switch comprising: at least one input port for launching a beam of light into the optical switch; at least two output ports for selectively receiving the beam of light; a lens having a focal length approximately equal to the Raleigh range of the beam of light incident thereon; a first array of deflectors and a second array of deflectors for switching the beam of light from the at least one input port to a selected one of the at least two output ports wherein the switching is performed along an optical path including the first and the second array of deflectors and the lens and wherein the beam of light passes five times through the lens when switching the beam to a selected one of the at least two output ports.

Brief Description of the Drawings

Exemplary embodiments of the invention will now be described in conjunction with the drawings in which:

Fig. 1 is a schematic presentation of a prior art optical switch having a Z-shaped arrangement of optical components;

Fig. 2 shows a schematic presentation of an optical switch in accordance with the present invention;

Fig. 3 is a schematic presentation of an exemplary optical path for a beam of light being switched from an input port to a selected output port;

Fig. 4 shows a schematic presentation of a preferred embodiment of the optical switch in accordance with the present invention including a GRIN lens;

Fig. 5 shows a schematic presentation of an array of micro-mirrors provided on a MEMS chip;

Figs. 6a-6c show a schematic presentation of a Gaussian propagation of the beam of light through a GRIN lens when tilted by -7° (Fig. 6a), 0° (Fig. 6b) and +7° (Fig. 6c); and

Fig. 7 shows a quintuple ATO switch in comparison to an "Astarte-like" switch.

Detailed Description of the Invention

The present invention expands on the optical switch disclosed in CA X,XXX,XXX (10-384 CA and 10-412 CA). It develops the optical architecture of large optical crossconnect structures and applies it to medium and small scale switches to provide very compact optical switches. For this purpose, a micro-mirror array of independently 2D tiltable micro-mirrors on a MEMS chip is used in conjunction with an angle-to-offset lens to provide a switch fabric in a miniaturized space. The waveguides or fibers are fed through the MEMS chips themselves for compactness, while a single common fixed mirror is added on each opposite MEMS chip for targeting purpose.

Turning now to Fig. 1 a schematic presentation of a prior art optical switch 100 having a Z-shaped arrangement of optical components is shown. A beam of light 102 enters the switch and is reflected by a first fixed mirror 104 towards a first 2D mirror 106. The 2D mirror 106 reflects beam 102 towards a second 2D mirror 108 which in turn reflects beam 102 to a second fixed mirror 110. The second fixed mirror 110 then reflects beam 102 towards an output port 112. Fig. 1 clearly shows that beam 102 follows the standard Z-shaped approach for switching an optical signal. The Z-shape approach requires particular consideration with respect to the physical spacing between the optical elements

since the beam of light should not be obstructed by some elements along the optical path through the switch. It is apparent that this is not a very efficient design.

As is seen, an array of 2 mirrors is used to steer the beam in transmission; a first fixed mirror is used to redirect the beam to a second 2D tiltable mirror that provides beam steering. In accordance with the present invention, each fixed mirror is replaced with a common mirror placed at the opposed focal planes of the ATO lens and share this common fixed mirror for every port. The optical switch in accordance with the present invention requires two common fixed mirrors, one for the input ports and one for the output ports. Such an arrangement allows to work with normal incidence on mirrors (reduced PDL) and provides a higher fill factor than prior art optical switches, for example a fill factor of close to 50% is achieved as in comparison to prior art fill factors of approximately 30%.

Fig. 2 shows a schematic presentation of an optical switch 200 in accordance with the present invention wherein the optical elements are arranged in-line. This results in a more compact design of optical switch 200. Switch 200 includes an input port 202, an angle-to-offset (ATO) lens 203, a first array of deflectors 204 including a first fixed deflector 206 and a first plurality of 2D tiltable deflectors 208, a second array of deflectors 210 including a second fixed deflector 212 and a second plurality of 2D tiltable deflectors 214. The first and the second array of deflectors 204 and 210 can be an array of micro-mirrors tilting in two perpendicular directions and one fixed micro-mirror. The ATO lens 203 has a focal length 205 which corresponds to the near zone length (multimode) or the Rayleigh range (single mode) of a beam of light incident thereon. A more detailed description of the ATO principle is provided below. The first array of deflectors 204 is arranged in a first focal plane of the ATO lens 203 and the second array of deflectors 210 is arranged in a second focal plane of the ATO lens 203. A plurality of output ports 216, 218, 220, and 222 is shown to be arranged on the first array 204.

Turning now to Fig. 3 a schematic presentation of an exemplary optical path for a beam of light being switched from an input port 302 to a selected output port 320 is shown, as

it travels through optical switch 300. A beam of light 301 is launched into the optical switch 300 at input port 302. Input port 302 is arranged on a second array of deflectors/MEMS chip 310. Beam 301 traverses through an ATO lens 303 and is directed to a first fixed mirror 306 which is arranged on a first array of deflectors/MEMS chip 304. The first fixed mirror 306 then reflects beam 301 to an independently 2D tiltable micro-mirror 314 on MEMS chip 310 by going back through lens 303. As is seen from Fig. 3, beam 301 comes off at an angle when it is reflected by the first fixed mirror 306 and from the lens 303 it is directed parallel to an optical axis until beam 301 reaches micro-mirror 314. Micro-mirror 314 is tilted to reflect beam 301 to micro-mirror 308 which is arranged on the first MEMS chip 304 by going back through the lens 303. Micro-mirror 308 sends the beam 301 back in parallel to the optical axis by going through lens 303 and then beam 301 collapses onto the second fixed mirror 312 arranged on the second MEMS chip 310. The second fixed mirror 312 distributes beam 301 to output port 320 by going through lens 303. It is apparent from Fig. 3 that lens 303 is used multiple times as beam 301 has traveled 5 times therethrough. This means that lens 303 fulfils the function of a first telecentric relay, switching, and a second telecentric relay. By using a same lens multiple times a very compact optical switch is provided. However, in order to accomplish such a compact design, the input and output ports are provided directly on the second and first MEMS chip, respectively. The mirrors and the input/output ports share the available space on the MEMS chips and hence optical switches in accordance with the present invention have a low fill factor. As a result of the low fill factor and the maximum packing density on the MEMS chip, the present invention is used to provide very compact small scale switches, such as compact 16x16, 32x32, or 64x64 switches.

The present invention is also applicable to large optical switches/crossconnects, but the compactness advantage of having the coupling optics folded into the main switch pass, as opposed to the standard Z-shape approach, starts to be less attractive than getting a higher fill factor.

The input and output ports can consist of optical fibers coupled to collimator lenses. Depending on the material used for making the MEMS chip, the beam of light can be launched directly through a transparent region of the MEMS chip, i.e. a region unobstructed by a micro-mirror, or a passage in form of a hole is provided on the MEMS chip to allow the beam of light to pass therethrough. If silicon or silica are used as a MEMS material, the light can be send directly through the MEMS chip since both silicon and silica are transparent in the infrared region, and in particular at 1.55 microns. However, gallium arsenide (GaAs) or indium phosphide (InP) are preferred materials for photonic applications, e.g. lasers, detectors, etc., but they are not transparent at 1.55 microns. In this case, a passage is provided on the MEMS to allow the beam of light to pass therethrough.

Fig. 4 shows a schematic presentation of a preferred embodiment of an optical switch 400 in accordance with the present invention wherein the ATO lens is a GRIN lens 402. This embodiment provides an even more compact optical switch. GRIN lens 402 is a ¼ pitch SLW 3.0 SELFOC™ lens having a length of 7.89 mm. A 4x4 SMF input fiber bundle 404, is shown on the left of Fig. 4. It has a pitch of 250 μm. A micro-lens array 406 is disposed on the input fiber bundle 404 to expand the beams to an appropriate diameter. Exemplary dimensions of this micro-lens array 406 are a diameter of 125 μm, a pitch of 250 μm, and an efl of 415 μm. A first array of micro-mirrors 408 including a first common fixed mirror and a first plurality of independently 2D tiltable micro-mirrors is disposed between the micro-lens array 406 and a first end face 410 of lens 402. The dimension of the first array of micro-mirrors 408 is 125x125 μm^2, +/- 3.4°, +/- 0.2°. The first end face 410 corresponds to a first focal plane of the lens 402. A second end face 412 corresponding to a second focal plane is located on an opposed end face of lens 402. A second array of micro-mirrors 414 including a second common fixed mirror and a second plurality of independently 2D tiltable micro-mirrors is provided at the second end face 412. An output fiber bundle 418 having an array of micro-lenses 416 arranged thereon is disposed at the second array of micro-mirrors 414. The first and the second array of micro-mirrors 408 and 414 are disposed on MEMS chips. These MEMS chips are mounted in the first and second focal plane of the GRIN lens 402, for example by

gluing them to the lens 402. Since lens 402 is an ATO lens its focal length corresponds to the near zone length (multimode) or Rayleigh range (single mode) of a beam light incident thereon. The array of micro-mirrors 414, the array of micro-lenses 416, and the SMF output fiber bundle have the same dimensions as the respective array of micro-mirrors 408, the array of micro-lenses 406, and the SMF output fiber bundle 404 which results in an overall dimension for optical switch 400 of 11 mm x 3 mm diameter, excluding the fiber bundles; a very compact optical switch. The total length of the lens 402 corresponds to 2f, wherein f is the focal length of the lens.

Using a conventional GRIN lens, such as a SELFOC™ SLW 3.0 lens, as the main optical element allows to build a very compact switch and further potentially eases the packaging since conventional coupler-like assembly techniques can be used. The overall footprint for a 16x16 optical switch is less than 11 mm long and 3 mm in diameter excluding the fiber bundles, standard SMF28 on 250 μm pitch.

As was explained above, the beams of light can be launched through the MEMS substrate directly if it is made of silicon. However, for certain applications other MEMS substrates may be desired which are not transparent to the beams of light. In such a case, a passage or hole is provided on the substrate to allow the beams of light to pass through the MEMS chips.

In accordance with another embodiment of the present invention, the GRIN lens 402 is foreshortened to create room for the optical components disposed at the respective end faces of the GRIN lens 402. A foreshortening of the GRIN lens maintains the focal plane of this lens but moves the lens away from the space of the focal plane to accommodate the array of micro-mirrors.

Fig. 5 shows a schematic presentation of an array of micro-mirrors provided on a MEMS chip 500 as disposed on a GRIN lens for example. A common fixed mirror 502 is shown in the center of Fig. 5. The fixed mirror 502 is surrounded by an array of 4x4 of independently 2D tiltable micro-mirrors 504 and beams of light 506 are shown in

between neighboring micro-mirrors 504. Exemplary dimensions of MEMS chip 500 are presented in Fig. 5.

In the following a rough tolerancing example for optical switch 400 at 0.5 dB extra loss is presented. An overall insertion loss is smaller than 1 dB and is mainly due to mirror losses assuming 96% gold. The SELFOC™ usage is NA ~ 0.24 / SLW 3.0 recommended for NA < 0.46. Switch 400 has an insertion loss uniformity of ~ 0.2 dB which is mainly due to off-axis aberrations. A 1D look-up table is assumed. The position of the MEMS chip with respect to the SELFOC™ lens is +/- 8 microns. Switch 400 has a pointing accuracy of +/- 0.25° or +/- 3.6% of range or +/- 7.2% of half-range. The focal length of the micro-lenses is 415 μm and has a tolerance of +/- 16%. The length of the SELFOC™ lens is 7.89 mm and has a tolerance of +/-9%. It can be polished to fit the MEMS chip if needed. The SMF fiber location with respect to the micro-lens array is +/- 1.8 μm. The parallelism of the SELFOC™ facets can be compensated for by alignment of the MEMS chip with respect to the SELFOC™ lens. The architecture is scalable but a 16x16 architecture is optimal for use with the described SELFOC™ lens. In summary, the design of optical switch 400 is very tolerant as the losses are very small, aberrations are very small, it has a very good loss uniformity, a simplified look-up table, the position of the MEMS chip with respect to the lens is easy to meet, it has a good pointing accuracy, the focal length is easy to meet.

Figs. 6a-6c show a schematic presentation of a Gaussian propagation of the beam of light through a GRIN lens when tilted by -7° (Fig. 6a), 0° (Fig. 6b) and +7° (Fig. 6c). Figs. 6a to 6c show that the GRIN lens is in agreement with the ATO lens principle in that a certain input mode is maintained at the output. For example, Fig. 6a shows that when a micro-mirror tilts a beam of light by -7° a negative position below the optical axis is reached at the opposed end face of the lens. If the micro-mirror tilts the beam by +7° a positive position above the optical axis is reached (Fig. 6c) and if the micro-mirror tilts the beam by 0° a position on the optical axis is reached (Fig. 6b).

Fig. 7 shows a quintuple ATO switch in comparison to an "Astarte-like" switch.

Below follows a description of the angle-to-offset (ATO) principle as described through Gaussian beam optics. The beam power of a Gaussian beam is principally concentrated within a small cylinder surrounding the beam axis. The intensity distribution in any transverse plane is described by a circularly symmetric Gaussian function centered about the beam axis. The width of this function is at a minimum at the beam waist and grows gradually in both directions. Within any transverse plane, the beam intensity assumes its peak value on the beam axis and drops by the factor $1/e^2$ at the radial distance $\rho = W(z)$. $W(z)$ is regarded as the beam radius or half the beam width, since about 86% of the beam power is carried within a circle of this radius $W(z)$. The dependence of the beam radius on z is described by the following equation:

$$W(z) = W_0\left[1+\left(\frac{z}{z_0}\right)^2\right]^{1/2}$$

The beam radius assumes its minimum value W_0 in the plane z = 0 which is called the beam waist, and hence W_0 is the waist radius. The beam radius increases gradually with z, reaching $\sqrt{2}W_0$ at $z = z_0$, and continues increasing monotonically with z. If $z \gg z_0$ then the first term can be neglected resulting in the following linear relation

$$W(z) \approx \frac{W_0}{z_0} z = \theta_0 z$$

wherein $\theta_0 = W_0 / z_0$,

using $W_0 = \left(\frac{\lambda\ z_0}{\pi}\right)^{1/2}$,

the following equation is obtained

$$\theta_0 = \frac{\lambda}{\pi\ W_0}.$$

Further, if $z \gg z_0$, i.e. far from the beam center, the beam radius increases approximately linearly with z, defining a cone with half angle θ_0. About 86% of the beam power is confined within this cone. The angular divergence of the beam is therefore defined by the divergence angle

$$\theta_0 = \frac{2}{\pi}\frac{\lambda}{2W_0}.$$

As is seen, the beam divergence is directly proportional to the ratio between the wavelength λ and the beam waist diameter $2W_0$.

The parameter z_0 is known as the Rayleigh range or near zone and denotes a distance where the area of the beam doubles. Thus,

if $$A_1 = 2A_0$$

and $$A_1 = \pi W_1^2 \text{ and } A_0 = \pi W_0^2$$

$$\pi W_1^2 = 2\pi W_0^2$$

$$W_1 = \sqrt{2}\, W_0$$

General Gaussian beam theory states that if the input waist of $1/e^2$ beam radius W_1 is placed at the front focal plane of a lens of focal length F then the output waist of $1/e^2$ beam radius W_2 is located at the back focal plane of the lens. The relationship between these radius sizes is shown in the following equation

$$W_2 = \frac{F\lambda}{\pi W_1}$$

It is apparent from this equation that the input beam size can be made equal to the output beam size by selecting an appropriate focal length F. This focal length is proportional to the square of the beam radius, and is equal to the Raleigh range of the input beam.

Thus, a so-called ATO lens is a lens having a focal length equal to the near zone (multimode) or the Rayleigh range (single mode).

Numerous other embodiments can be envisaged without departing from the spirit and scope of the invention.

Claims

What is claimed is:

1. An optical switch comprising:

at least one input port for launching a beam of light into the optical switch;

at least two output ports for selectively receiving the beam of light from an optical path between the at least one input port and a selected one of the at least two output ports;

a lens having a focal length approximately equal to the near zone length of the beam of light incident thereon;

a first array of deflectors including a first fixed deflector and a first plurality of independently tiltable deflectors and a second array of deflectors including a second fixed deflector and a second plurality of independently tiltable deflectors, wherein the first fixed deflector is for receiving the beam of light from the at least one input port via the lens and for deflecting the beam of light to one of the second plurality of independently tiltable deflectors via the lens, and the second fixed deflector is for receiving the beam of light from one of the first plurality of independently tiltable deflectors via the lens and for deflecting the beam of light to a selected one of the at least two output ports via the lens, and wherein the first and the second plurality of independently tiltable deflectors are for switching the beam of light.

2. The optical switch as defined in claim 1 wherein the first array of deflectors is disposed in a first focal plane of the lens and the second array of deflectors is disposed in and a second focal plane of the lens.

3. The optical switch as defined in claim 2 wherein the at least one input port, the at least two output ports, the lens, the first array of deflectors, and the second array of deflectors are arranged in-line.

4. The optical switch as defined in claim 3 wherein the beam of light passes five times through the lens along the optical path between the at least one input port and a selected one of the at least two output ports.

5. The optical switch as defined in claim 3 wherein the first array of deflectors and the second array of deflectors are disposed on a first MEMS chip and a second MEMS chip, respectively.

6. The optical switch as defined in claim 5 wherein the deflectors are micro-mirrors.

7. The optical switch as defined in claim 5 wherein the at least one input port and the at least two output ports are disposed at regions of the first and the second MEMS chip, respectively, which are transparent to the beam of light incident thereon.

8. The optical switch as defined in claim 7 wherein the first and the second MEMS chip are made of one of silicon and silica.

9. The optical switch as defined in claim 5 wherein the at least one input port and the at least two output ports are disposed at regions of the first and the second MEMS chip, respectively, having a passage for allowing the beam of light to pass therethrough.

10. The optical switch as defined in claim 9 wherein the first and the second MEMS chip are made of one of silicon (Si), silica (SiO_2), gallium arsenide (GaAs), and indium phosphide (InP).

11. The optical switch as defined in claim 2 wherein the lens is a focusing lens.

12. The optical switch as defined in claim 2 wherein the lens is a GRIN lens.

13. The optical switch as defined in claim 12 wherein the GRIN lens is a quarter pitch GRIN lens.

14. The optical switch as defined in claim 13 wherein the first array of deflectors is disposed at a first end face of the GRIN lens and the second array of deflectors is disposed at a second end face of the GRIN lens.

15. The optical switch as defined in claim 14 wherein the GRIN lens is a foreshortened GRIN lens for accommodating the first array of deflectors in the first focal plane of the GRIN lens and the second array of deflectors in the second focal plane of the GRIN lens.

16. The optical switch as defined in claim 1 wherein the optical path is a path from the input port via the lens to the first fixed deflector, from the first fixed deflector via the lens to the one of the second plurality of independently tiltable deflectors, from the one of the second plurality of independently tiltable deflectors via the lens to the one of the first plurality of independently tiltable deflectors, from the one of the first plurality of independently tiltable deflectors via the lens to the second fixed deflector, and from the second fixed deflector via the lens to the output port.

17. An optical switch comprising:

at least one input port for launching a beam of light into the optical switch;

at least two output ports for selectively receiving the beam of light;

a lens having a focal length approximately equal to the Raleigh range of the beam of light incident thereon;

a first array of deflectors and a second array of deflectors for switching the beam of light from the at least one input port to a selected one of the at least two output ports wherein the switching is performed along an optical path including the first and the second array of deflectors and the lens and wherein the beam of light passes five times through the lens when switching the beam to a selected one of the at least two output ports.

18. The optical switch as defined in claim 17 wherein the first array of deflectors includes a first fixed micro-mirror and a first plurality of tiltable micro-mirrors, and the

second array of deflectors includes a second fixed micro-mirror and a second plurality of tiltable micro-mirrors.

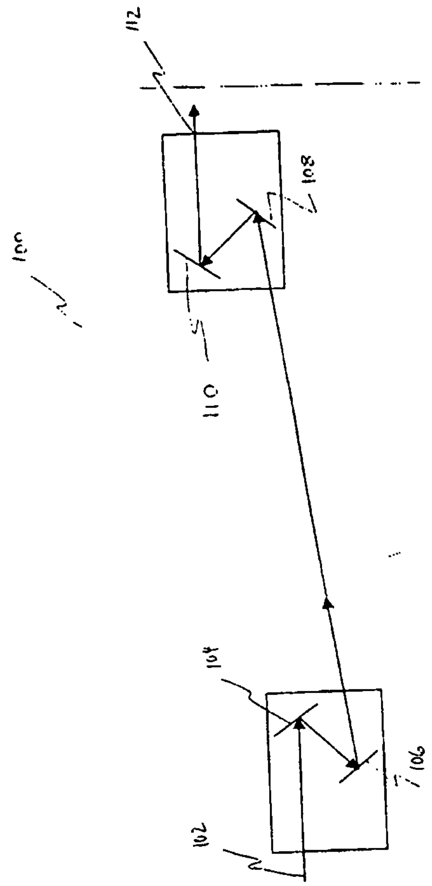
19. The optical switch as defined in claim 18 wherein the at least one input port, the at least two output ports, the lens, the first array of deflectors, and the second array of deflectors are arranged in-line.

20. The optical switch as defined in claim 19 wherein the first array of deflectors and the second array of deflectors is disposed on a first MEMS chip and a second MEMS chip, respectively.

21. The optical switch as defined in claim 20 wherein the at least one input port and the at least two output ports are disposed at regions of the first and the second MEMS chip being transparent to the beam of light incident thereon.

22. The optical switch as defined in claim 21 wherein the transparent regions are passages for allowing the beam of light to pass therethrough.

23. The optical switch as defined in claim 17 wherein the first array of deflectors is disposed in a first focal plane of the lens and the second array of deflectors is disposed in a second focal plane of the lens.



PRIOR ART

Fig. 1

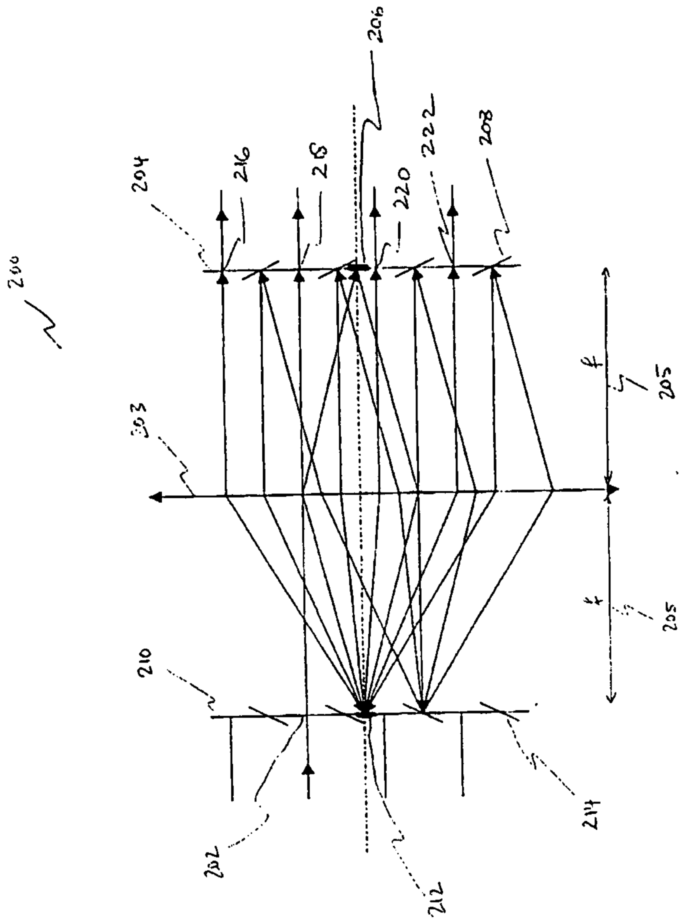


Fig. 2

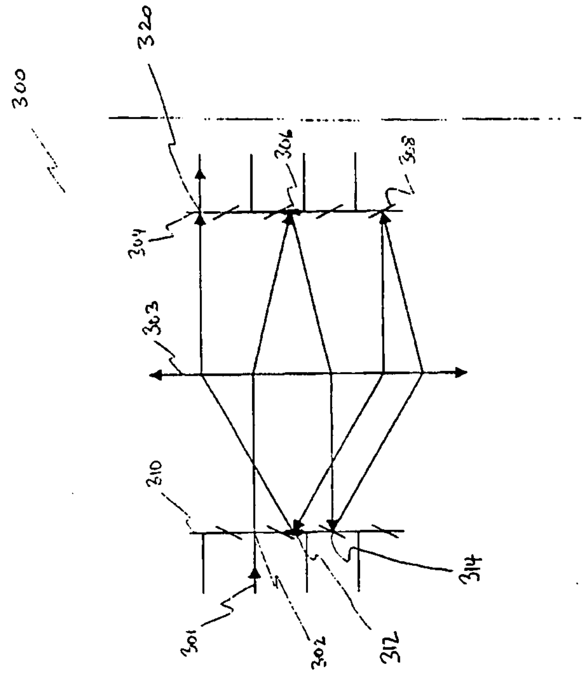


Fig. 3

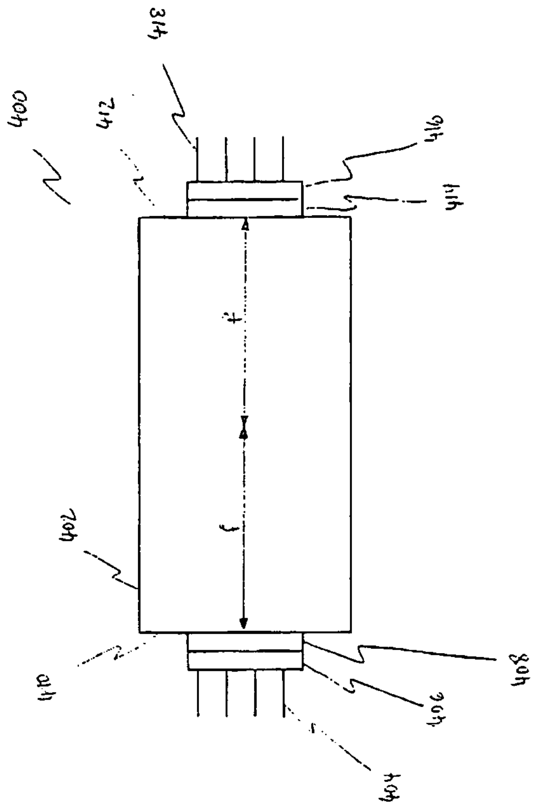


Fig. 4

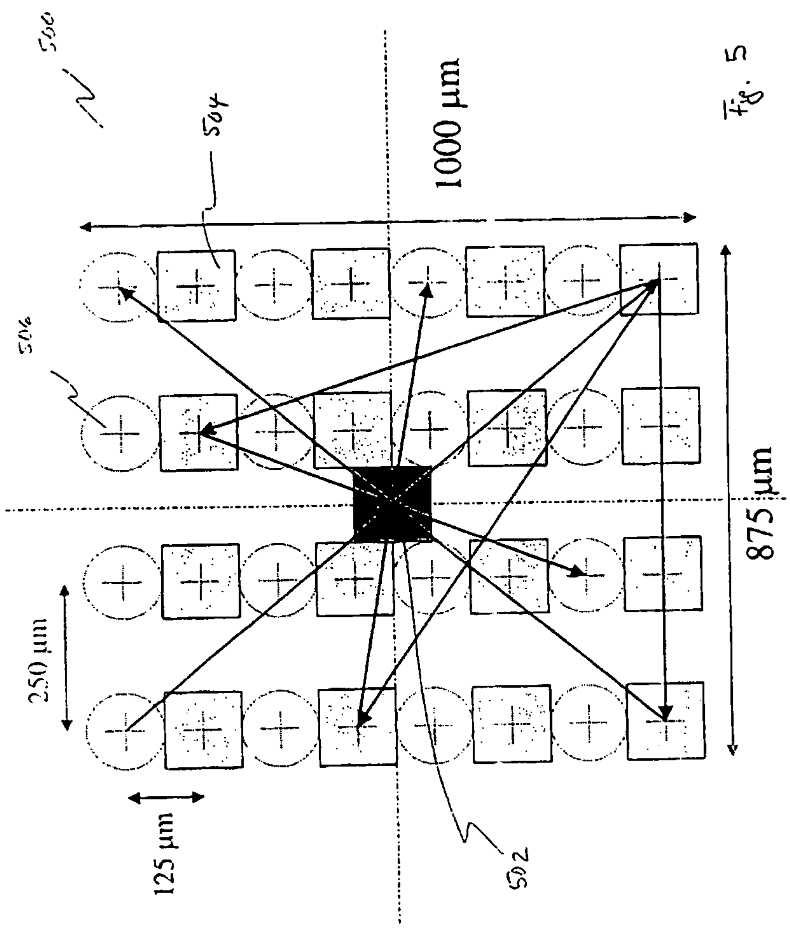


Fig. 5

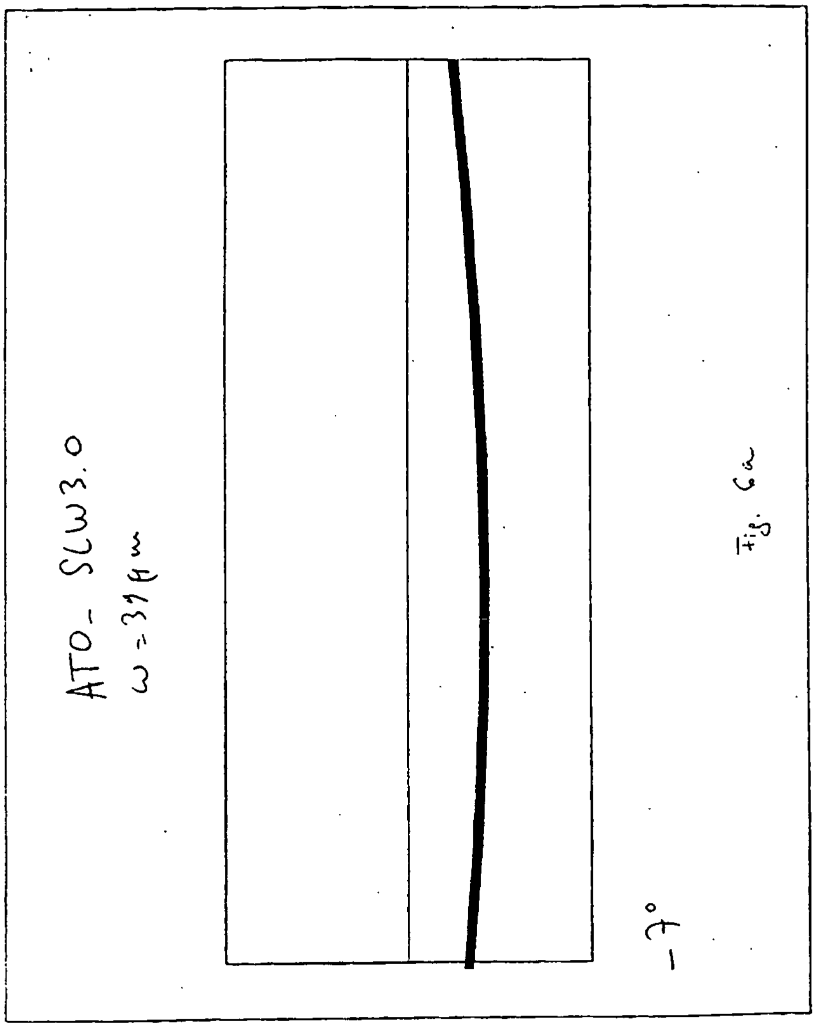


Fig. 6a

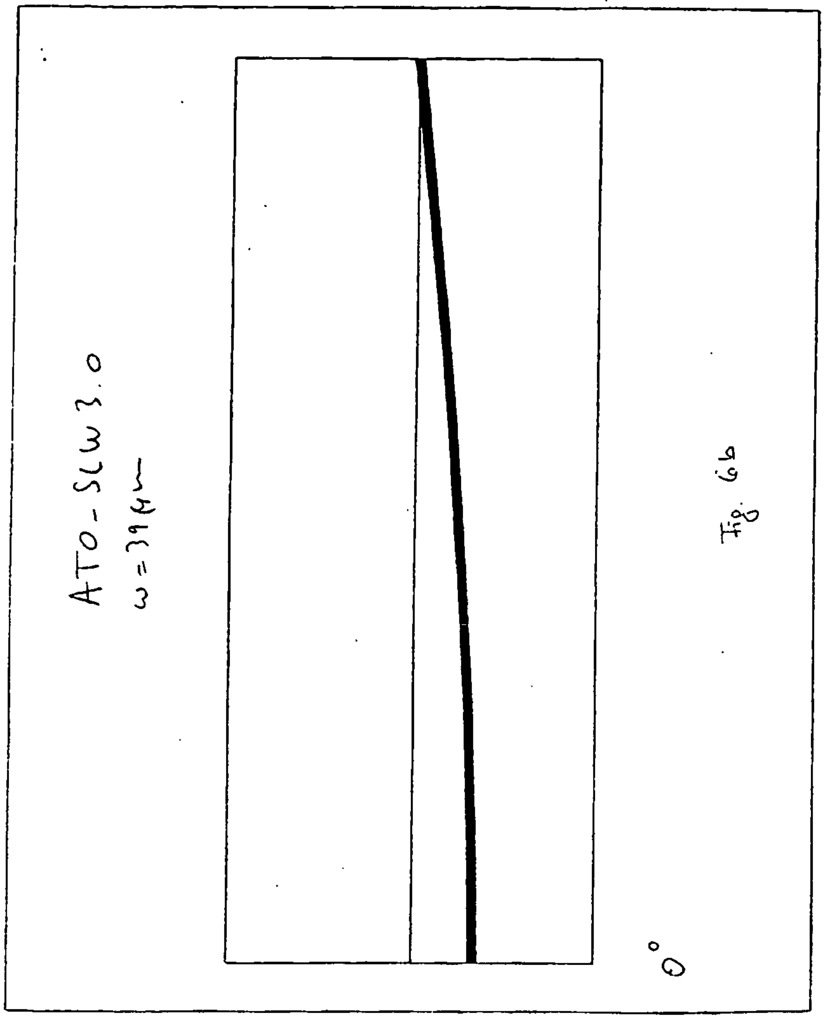
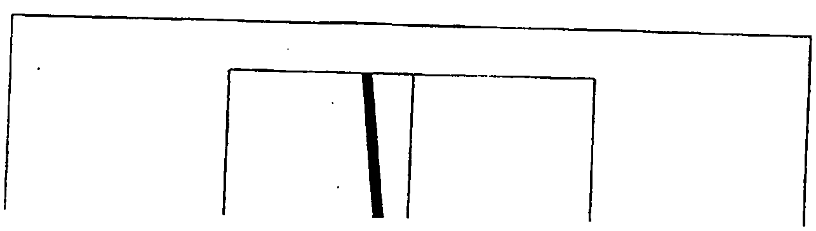


Fig. 6b



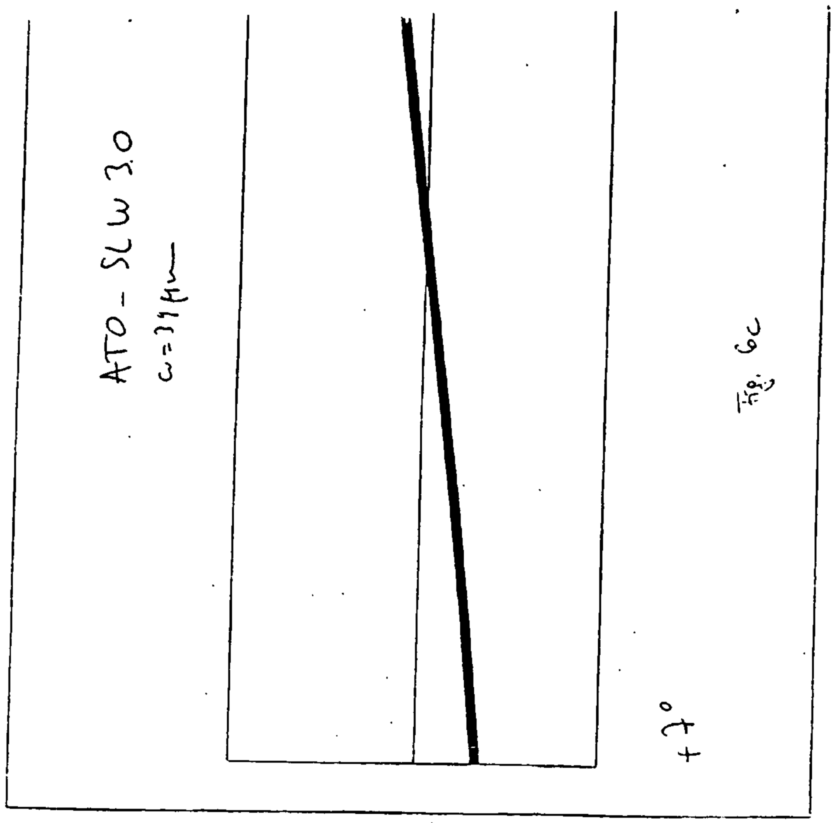


Fig. 6c

Fig. 7

QUINTUPLE
~~Triple~~ ATO vs "Astarte-like"

- Single common fixed mirror
- No clearance required from fixed to 2D mirror due to tilting
- Near normal incidence on mirrors (reduced PDL)

=> More compact (example for 1024x1024, +/- 7.1°):
- Astarte-like: K = 30%
- Triple ATO: K = 50%